Advanced Experimental Techniques – Physics 493

Rules of the Road

(Plagiarized and adapted from the MIT Lab)

1. Usual Motivating Paragraph

The purpose of the Advanced Experimental Lab is to give you hands-on experience with some experiments of modern physics and, in the process, to deepen your understanding of the relations between experiment and theory. You will perform experiments on phenomena whose discoveries led to major advances in physics. It is surprisingly satisfying to observe, measure, and understand phenomena, many of which would have won you the Nobel Prize if you had discovered them. By the end of this course you may not yet be a scientist, but you will at least have learned how to *act* like a scientist: how to keep a real lab notebook, how to present your results to your peers, how to write a clear and interesting scientific article, and how not to get hurt in the lab.

2. The Basics

You will work by yourself or in pairs, sharing as evenly as possible in the measurements, the analysis and the interpretation of the data. Students will select approximately 4 different experiments to complete over the course of the semester. Most students find they require at least the full 6 hours per week in the lab for approximately 3 weeks to complete each experiment. At the completion of each experiment one student from each pair will give an oral presentation, and the pair will also jointly submit a written paper in the form of an article suitable for publication.

Preliminary Questions

Each experiment has a set of preparatory questions which point you to the essentials of the experiment. These questions are posted on our class web site. Before 7:00 pm on the day before of the first session of each experiment, each student must separately work out the answers to the preparatory problems and submit them via Blackboard. Some of the questions are not so easy, so give yourself sufficient time. You can write your solutions by hand and then scan them (use CamScanner first), or you can compose your solutions directly on a computer.

Prof. Feinberg will read your e-mailed solutions before your first experimental session. When you arrive in the lab that day, bring a copy of your solutions with you. **At the beginning of that class, Prof. Feinberg will discuss your solutions with you. If your solutions are satisfactory, then you can begin work on your experimen**t. However, if you failed to e-mail your solutions to Prof. Feinberg before 7:00 pm the previous evening, or if your solutions are hopeless, then you will not be able to begin your experiment in the lab that day. You will be labeled as a slacker, your lab partner (if you have one) will proceed with the experiment without you, and your grade in the course will suffer.

Experiments for Physics 493 – Spring 2020

Experiment	Prerequisite	Type*
Advanced Nuclear Magnetic Resonance	Earth's Field Nuclear Magnetic Resonance	Self-contained
Earth's Field Nuclear Magnetic Resonance		Self-contained
Fourier Techniques		Self-contained
Holography	Interferometry	Open-ended
Interferometry		Self-contained
Lock-In Detection		Self-contained
Magnetic Torque		Self-contained
Pair Production		Open-ended
Quantum Analogs		Self-contained
Speed of Light		Open-ended
Torsional Oscillator		Self-contained
X-Ray Diffraction		Self-contained
Zeeman Effect	A year of quantum mechanics: 438a and 438b	Open-ended

***Type:**

"Self-contained" experiments come with their own user manual and instructions.

"Open-ended" experiments do not have a user manual and therefore are somewhat more difficult, but they are often more interesting.

3. Ethical Behavior

When you read the report of a physics experiment in a reputable journal, you generally assume that it represents an honest effort by the authors to describe exactly what they observed. You may doubt their interpretation or the theory they cite to explain their results. But at least you trust that if you repeat the manipulations as described, you will get essentially the same experimental results. Nature is the ultimate enforcer of truth in science. If subsequent work proves a published measurement is wrong by substantially more than the estimated error limits, a reputation shrinks. <u>If fraud is discovered, a career is ruined.</u> So most professional scientists are very careful about the records they maintain and the results they publish.

This Lab is designed to provide pre-professional training in the art and science of experimental physics. What you record in your lab book and report in your written and oral presentations must be exactly what you have observed, including date, time and who did it. Sometimes you'll get things wrong because of an error in manipulation, equipment malfunction, misunderstanding, or a miscalculation. Simply cross out errors using a diagonal line in your notebook and start again. <u>Don't erase.</u> An example of a well-kept lab notebook will be available in the lab for you to scrutinize.

The instructor's job is to help you figure out what went wrong so you can do better next time. Fabrication or falsification of data, or using the results of another person's work without acknowledgement, are intellectual crimes as serious as plagiarizing a term paper, and possible causes for dismissal from USC. The precaution about acknowledging other people's data also applies to acknowledging other people's ideas in your written reports. The best way to incorporate an idea that you have learned from a textbook or other reference is to study it until you understand it, and then put the text aside and state the idea in your own words.

In a scientific journal one often sees phrases such as "Following Albert Einstein ..." This means that the author is following the ideas or logic of Einstein, not his exact words. If you quote material, it is not sufficient merely to include it in the list of references at the end of your paper. The quote should be indented on both sides or enclosed in quotes, and attribution must be given immediately in the form of a reference.[1] Importing text from a published work, web sites (for example, parts of this handout are plagiarized from MIT), other student papers, or from lab guides without proper attribution is a serious breach of ethics and will be dealt with by the Committee of Academic Discipline.

The purpose of these physics experiments is to give you hands-on experience with the manipulation of atomic and nuclear phenomena, a sense of the reality of the concepts and theories you have studied in books and lectures, and the beginning of professional skill in obtaining and recognizing reliable data and extracting meaningful results from them. (That's a long sentence.) There is nothing wrong with "peeking" in the CRC Handbook or Wikipedia or any of the many relevant sources to see what results your experiment should have yielded. In fact, in your conclusions, you will compare your values to established results. If the established value is outside your error range, try to find out what went wrong, fix it, and try again. If the established value is within your error range, don't rest easy, but do whatever may be necessary to prove it isn't an accident. Repetition is the essential key to attaining confidence in a result, whether of a single measurement or

[1] Like this one.

an entire experiment. But whatever is the outcome of an experiment, you must describe exactly what you observed or measured when you present your oral or written report, regardless of how “bad” the results may appear to be.

4. Lab Attendance

You are required to attend the lab session for the full three-hour period twice each week. If a medical problem forces an absence, bring a signed medical note when you return. Any exception must be approved by Professor Feinberg. Also, if high voltages are involved, a partner or instructor must always be within reach.

5. Grading Policy

Your grade will be computed using the following percentages:

Lab attendance and your effort in lab	**20**
In-class presentations	**15**
Laboratory notebook	**25**
Written pre-lab solutions	**15**
Written reports	**25**

Attendance

The regularity of your attendance will be a factor in determining your grade in the course. Your preparedness and attitude will also count towards your grade. It is essential that you efficiently use all (and sometimes more) of the allotted laboratory time.

Oral Presentation

Every 3 or so weeks every student (or pair of students) will prepare and present a 20-minute oral report on the theoretical and experimental aspects of their experiment. If two students worked together, then the report will be presented by only *one* student of the pair.

Students are expected to delve deeply into the underlying physics and the results of their experiment. You will prepare your presentation electronically (using PowerPoint, for example) and use the class LCD projector for the cleanest, most professional presentation possible. The finished presentation must be posted to Blackboard *before* it is presented to the class.

The theoretical section of your presentation should demonstrate a mastery of some portion of relevant theory. The larger experimental section should demonstrate an understanding of how the equipment works, what was measured, how the data were reduced, and how random and systematic errors were estimated. Each oral presentation must discuss motivating theory and experiment; it is not acceptable to discuss only theory or only experiment. Full cooperation is encouraged between lab partners in preparing for the oral reports.

4-Page (or more) Written Papers

Each experimenter or group must prepare and submit via Blackboard a PDF copy of their 4-page (or more), collectively-written paper on the purpose, theory, and results of their experiment before midnight on the first Saturday following their oral report. The delay between oral presentation and paper submission allows each person (or pair) to correct any egregious mistakes that were uncovered during their oral presentation so as not to repeat those mistakes in their written work and receive a double penalty. (The delay also gives you time to prepare your paper, which takes longer than you might think. Plan accordingly!)

All your work on the experiment should be discussed in your paper, not only the part you chose for your oral presentation. Your paper should show evidence of your own mastery of the entire experiment and possess a neat appearance with concise and correct English. (If your English is poor, persuade a friend to proofread your paper before you submit it.) Your paper's organization and style should resemble that of a typical article in the Physical Review Letters (http://prl.aps.org/) or Optics Letters. A sample paper is posted on Blackboard.

An Abstract is essential. It should briefly mention the motivation (purpose), the method (how measured) and most important, the quantitative result WITH uncertainties. Your Abstract should also state your conclusions.

The bulk of the paper should include a discussion of motivation and the theoretical issues addressed by the experiment, a description of the apparatus and procedures used, a presentation of the results (including errors!), a discussion of these results, and, finally, a section briefly presenting your conclusions. This last section reinforces what was stated in your abstract.

Your paper will be easier to read if you include figures in-line within the text, as shown in the sample paper. However, do not inundate the reader with material; you should find a way to summarize your results in at most three or four plots or tables. The plots and tables must be properly captioned; and each caption must describe the figure completely. As the semester progresses, you are welcome to reference and discuss any previous work by your fellow students. Material and ideas drawn from the work of others must be properly cited, and a list of references should be attached to the summary.

6. Laboratory Notebooks

One critical objective of this course is to instill habits of record keeping that will serve you well in future research. To this end you will use a standard experimental notebook in which you keep the complete dated record of procedures, events, original data, calculations and results of every experiment. If you work with a lab partner, *both* persons need to produce their own *complete* record and analysis of that experiment.

Your lab notebook should tell a complete story: What you are trying to do, what you actually did, what results you obtained, and what conclusions you made. You must write a sufficient narrative as the experiment proceeds so that, years later, you could understand the results you obtained and not wonder what you were doing or why you did it. Notes, tables, and graphs should be neat and compact, leaving as little empty space in the lab notebook as is compatible with clarity and the logic of organization. The lines in your notebook are convenient for making tables, and for guiding line drawings and making rough plots. High-resolution plots, photos, and photocopies of data shared between lab partners should be glued or taped in place. <u>There should be no loose sheets or graphs floating around.</u>

Analyze data in the lab in a preliminary way as you go along to check for reasonableness. **If you are making a series of measurements of one quantity as you vary another, plot the results as you go along so that you can see the trend, catch blunders, and judge where you may need more or less data.** Repeat every important measurement at least two times in as independent a manner as possible to establish a statistical basis for estimating random error and to reduce the chance of blunders. If during class you get through all the manipulations, measurements, and preliminary analysis of an experiment and have extra time, take that opportunity to perfect part or all the experiment to obtain the best possible data set.

In some experiments your data will be acquired by a computer and stored in files on disk. In these cases, is not practical to print out all your data and paste them into your notebook. However, you should (physically) paste into your lab notebook representative plots or tables. In addition, you should write in your lab notebook a clear description and summary of your data files, so that when you return to your electronic data days or weeks later you will be able to identify which particular files you used. Don't trust your memory; it will always fail you.

Analysis and Conclusion: Notebooks are not just for recording facts; they must tell a story. Towards the end of each experiment you should write a summary of your principal results in your lab notebook. <u>Data plots that you prepare for your written paper or oral presentation should also be taped into your lab notebook.</u> You should also record your thoughts about what may have gone wrong in your experiment and what might be done to fix it.

Your lab notebooks will be inspected periodically throughout the semester and will be graded by Prof. Feinberg at the end of the semester.

7. Safety

Since it is virtually impossible to set up a reasonably comprehensive and interesting set of experiments in modern physics without using equipment that is potentially hazardous, it is essential that students be aware of the hazards and exercise appropriate cautions. Prevention of injury is a matter of being aware of, and having respect for, pieces of equipment that are potentially dangerous.

High Voltage

- <u>The first rule is never to work alone</u>. Some years ago, a student was electrocuted at MIT by a laboratory power supply. Had he not been by himself, someone might have saved him.

- Remember that it is current that kills. A good (e.g. sweaty) connection of 30 volts across your body can kill as well as a poor connection at 6000 volts. If a fellow student is frozen to an electrical source by an electric current, use momentum transfer (tackle them!) to release him or her, and then have a trained person start CPR if needed.
- All high-voltage supplies are dangerous. Do not poke or probe into them. Turn off the supply if you need to change cable connections. Make sure the output voltage of the power supply measures zero before you mess with it; *a power supply may be dangerous even when turned off* if internal capacitors have not fully discharged.
- Always keep one hand in your pocket when testing any circuit in which there may be high voltages present, so that if you get a shock it will not be across your chest.
- Never go barefoot in the lab.

Lasers

The "Speed of Light" experiment utilizes a green laser, and the "Interferometry" experiment uses a red laser. <u>Do not look directly into these laser beams.</u> A laser beam may not seem very bright, but if it enters your eye it will be focused by your eye's lens to a pinpoint spot on your retina where the light intensity may be sufficient to destroy retinal cells. Experiments should be set up so that laser beams are directed parallel to the floor at about waist height so that any stray reflections hit your stomach instead of your face. It is wise to terminate a laser beam with a light blocker (cardboard works well) so that the beam doesn't careen around the lab and hit someone else in the face. Never examine the performance of an optical system containing a laser by bending over to put your eye on the same level as the laser beam.

Cryogenics

Liquid nitrogen is chemically inert, but it can cause severe frostbite. Wear gloves and protective glasses when transferring or transporting liquid nitrogen. Also, don't mix water and liquid nitrogen in a vessel; the water can freeze, form an ice plug, and then explode.

Chemicals

Don't ingest them. Clean up any spills immediately. Wash your hands after using them.

Shoes

No sandals or flip flops are allowed in the lab. Human toes don't grow back.

Food and Drinks

You are in California. Go outside.